ON THE DISTRIBUTION OF THE VARIOUS CHEMICAL GROUPS OF STARS.[1]

SOME few years ago it was my duty to give a course of lectures here relating to the sun's place in nature. I attempted to give an idea of the relation of the sun, as to age and temperature, to other stars, and also its relation to bodies supposed to be of a different order altogether.

Since that lecture was delivered our knowledge on this and allied subjects has advanced with giant strides. We now know, thanks to spectrum analysis, the principles of which I then explained, a great deal of the chemistry of the stars, so much that we can now classify them into groups, defining those groups by the chemical elements involved in each. I shall not bring before you to-night the detailed classification of these bodies, but shall, for the purposes of this lecture, ask you to consider the four following kinds only:

Highest temperature.

Gaseous stars { Proto-hydrogen stars. Cleveite-gas stars.
Proto-metallic stars.
Metallic stars.
Stars with fluted spectra.

Lowest temperature.

The table almost explains itself: I may add that by "proto-metallic" stars I mean those stars in the spectra of which the metals we know here are chiefly represented by lines—the so-called "enhanced-lines"—we can only obtain here by using high-tension electricity, and there are other evidences which show that these stars are hotter than the metallic ones, while they, in their turn, are cooler than the gaseous stars. In discussing the work of other observers I have as far as possible transposed the different notations employed into the chemical one given above.

In relation to the sun's place we had a great many comparisons to make with different stars quite independently of their position in space. I propose now to touch upon a still more general inquiry to consider the distribution of all stars in space, not in relation to their magnitudes, but in relation to their chemistry.

It is obvious that we are among the first from the beginning of the world who have been able to do this, because formerly the chemistry of these celestial bodies was entirely lacking. I think, therefore, you will agree that it is a very important thing, now that we have the chemistry, to inquire into the distribution of the various chemical conditions in the different parts of the universe in which our lot is cast. For that purpose, I will deal with the stars as generally as I can, considering only the wider division into the gaseous stars, the proto-metallic stars, that is to say, the stars represented by the enhanced lines, then the metallic stars in which we are dealing with arc lines, and then the metallic fluting stars and the carbon fluting stars. As star-life begins with nebula and meteoritic swarms, it ends with dark stars which it is possible may be very numerous in space. How many there are we do not know, because we cannot see them; but there are reasons for supposing that there is a very considerable number.

We have only to deal with the masses of matter in space which are visible, and it is obvious that any inquiry into the distribution of the chemical conditionings, as revealed by spectra, of these masses must be preceded by an inquiry into the distribution of these masses considered merely as masses and quite independent of chemistry.

This work has already occupied the attention of many eminent astronomers, and I will begin by placing the results of their labours before you as shortly as I can.

I call your attention to the Milky Way. If you have seen the Milky Way from a high mountainous country, as I have done, you will acknowledge what a very wonderful thing it is; I was most struck with the Milky Way when I was in the Rocky Mountains some years ago. It was not merely the pale milky belt we generally see running across the sky, but it had lights, shades, shadows, brightnesses and dimnesses; it was full of the most marvellous details. I have seen it, I am bound to say, just as well on the coast of Kent, but not often. You want an extremely fine sky to see the Milky Way properly; but, at all events, whether you have seen it well or ill, all of you, I am sure, are familiar more or less with it. What is it? It is a bright belt encircling the heavens; its position with regard to the equator of the earth, and the equatorial plane extended to the stars, I can show you roughly by means of a glass globe. Those who are familiar with Dante know that the old view of the heavens was that the earth was immovable in the

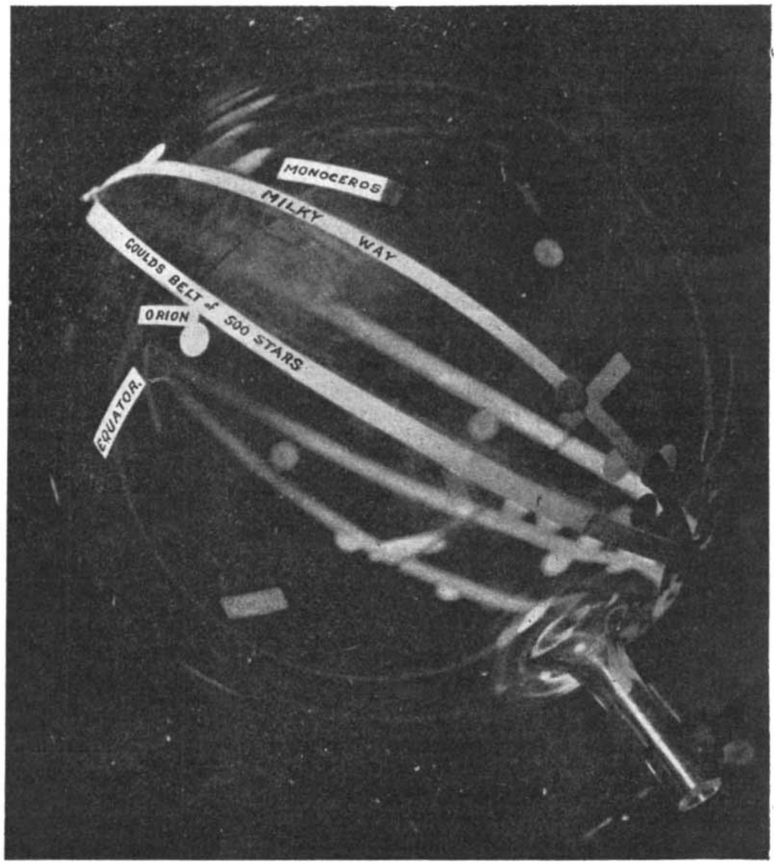

FIG. 1.—Photograph of a glass globe showing the relation of the Milky Way to the Equator and to Gould's belt of stars.

[1] A Lecture to Working Men, delivered at the Museum of Practical Geology, on April 10, by Prof. Sir Norman Lockyer, K.C.B., F.R.S.

centre; that there were several heavens round it: the heaven of the moon, the heaven of Venus, of Mars, and so on, till at last there was a heaven of the stars, a crystalline sphere to which the stars were fixed like golden nails. Let the glass globe represent this crystalline sphere.

The Milky Way is a great circle inclined, at an angle of about 62°, to the earth's equator or to the equatorial plane extending to the stars. We know nothing, of course, of the reason for that angle of 62°, but it has its importance, because not only must the belt cross the equator at two opposite points, as it does in two opposite constellations, Aquila and Monoceros, but the poles of the Milky Way must lie at the points of greatest distance from the junction with the equator, in certain constellations. These are Coma Berenices and Sculptor, and the position of the N. galactic pole, as the pole of the Milky Way is called, is in R.A. 12h. 40m. Dec. + 28°. Now, although the Milky Way looks very unlike the other parts of the heavens, we have known since the time of Galileo that the difference arises from the fact that it is composed of a tremendous multitude of stars; and this is why I have drawn attention to it, a very large percentage of the masses of matter which compose our system lies in the plane of the Milky Way. It does not merely represent a fiery or igneous fluid, as different schools thought it did in the old days. So far as our opera-glasses and telescopes indicate to us, we are in presence of an innumerable multitude of stars. When, however, we come to look at it a little more closely, we find that from two points in it branches are thrown out, so that over some part of its orbit, so to speak, it is double; there is a distinct doubling of the Milky Way along a part of its length. But in spite of that, the middle line of the galaxy or the Milky Way is really not distinguishable from a great circle, as was formerly supposed. The great rift which separates these two parts of it begins near a star in the southern hemisphere, α Centauri, and it continues for more than six hours in right ascension until the two branches meet again in the constellation Cygnus, which is well within our ken in the northern heavens. The distance apart of the middle lines of these two components of the Milky Way where the split is most obvious is something like 17°, so that, in addition to the angle of 62° from the ecliptic, in some part of the Milky Way, there is another offshoot springing out of it at an angle of something like 17°. The regions of greater brilliancy correspond approximately to the places where the branches intersect each other. In short, there are sundry indications that the whole phenomena of the Milky Way may become simplified by treating it as the resultant of two superimposed galaxies. The general view till recently was that the Milky Way is not a great circle, because it was thought the sun was not situated in its plane. The whole mass of stars was likened to a millstone split along one edge, which was Sir William Herschel's first idea. But the recent work, chiefly of Gould in Argentina, has shown that it practically is a great circle. However that may be, in one part of the heavens this wonderful Milky Way appears as a single, very irregular stream, and in another part it appears to be duplicated.

It is impossible in this short course of lectures to attempt to give anything like an historical statement of the growth of our knowledge of the Milky Way. I can only refer you to the Milky Way itself; and the next time any of you have an opportunity of seeing it, just look at the wonderful majesty and complexity of it. We find in it indications of delicate markings going out into space, apparently coming back strengthened, of streams in all directions, of clusters clinging to those streams, and so on. In other parts it is curdled, which is the only term which I can use to express my meaning. In another part we may find it absolutely free from any important stars; in another we may find it mixed with obvious nebula; and in another we may find it mixed, not only with obvious nebula, but with a great number of bright-line stars involved, not only in the Milky Way, but in the nebula itself.

We have now, fortunately for science, priceless photographs of these different regions. One will give us an idea of the enormous number of stars in some parts; another one of the streams of nebulous matter which are seen in the Milky Way from region to region. Again we find a regular river of nebulous matter rushing among thousands of stars. In some the galaxy seems to tie itself in knots. There is an individuality in almost every part of it, which we can study on our photographic plates; practically there are no two parts alike. Others again bring before us the curdled appearance which is visible in different regions, and finally the connection of the infinite number of stars with obvious nebulous matter. In this way, then, we are enabled to form an idea of the general conditioning of things as we approach the Milky Way.

The next important point is that the enormous increase of stars in the Milky Way is not limited to the plane itself, but that there is really a gradual increase from the poles of the Milky Way, where we get the smallest number of stars. It is not very easy to bring together all the information, for the reason that different observers give different measures; they take different units for the space they have determined to be occupied by stars from the pole towards the galactic plane; and also the number of stars in the northern hemisphere is not the same as the number in the southern hemisphere. But roughly speaking we may say, if we represent the number of stars at the galactic pole by four, the number of stars in the galactic plane will be about fifty-four.

The following table will show the gradual increase in the number of stars from the pole to the plane, as seen by the Herschels with a reflecting telescope of eighteen inches aperture and twenty feet focal length:— [1]

Galactic polar distance.	Average number of stars per field of 15′	
	Northern.	Southern.
0°–15°	4·32	6·05
15–30	5·42	6·62
30–45	8·21	9·08
45–60	13·61	13·49
60–75	24·09	26·29
75–90	53·43	59·06

A consideration of the distribution of stars in Right Ascension between declinations 15° N. and 15° S. led Struve to the conclusion that there are well marked maxima in R.A. 6h. 40m. and 18h. 40m., and minima in R.A. 1h. 30m. and 13h. 30m.; he remarks that the maxima fall exactly on the position of the Milky Way in the equator, and further states that "the appearance of the close assemblage of stars or condensation, is closely connected with the nature of the Milky Way, or that this condensation, and the appearance of the Milky Way, are identical phenomena."

Although the Milky Way dominates the distribution of stars, and especially of the fainter stars, it does not appear to be the only ring of stars with which we have to do. Sir John Herschel traced a zone of bright stars in the southern hemisphere, which he thought to be the projection of a subordinate shoot or stratum. That was the first glimpse of a new discovery, which was subsequently established by Dr. Gould in his work in the southern hemisphere at Cordova. He found that there was a stream of bright stars to be traced through the entire circuit of the heavens, forming a great circle as well de-

[1] *Outlines of Astronomy*, Herschel, pp. 535, 536.

fined as that of the galaxy itself, which it crossed at an angle of about 25°.

Gould, while in the southern hemisphere, had no difficulty in observing that along this circle, which we may call the Star-way, in opposition to the Milky Way, most of the brighter stars in the southern heavens lie.

When he subsequently came home he made it a point of study to see whether he could continue this line of bright stars among the northern hemisphere, and he found no difficulty. So that we may now say that the existence of this supplementary Star-way, indicated by the line of extremely bright stars, is beyond all question.

I quote the following from what Gould has written on this subject.[1]

"Few celestial phenomena are more palpable there than the existence of a stream or belt of bright stars, including *Canopus*, *Sirius*, and *Aldebaran*, together with the most brilliant ones in *Carina*, *Puppis*, *Columba*, *Canis Major*, *Orion*, &c., and skirting the Milky Way on its preceding side. When the opposite half of the galaxy came into view, it was almost equally manifest that the same is true there also, the bright stars likewise fringing it on the preceding side, and forming a stream which diverging from the Milky Way at the stars α and β *Centauri*, comprises the constellation *Lupus*, and a great part of *Scorpio*, and extends onward through *Ophiuchus* towards *Lyra*. Thus a great circle or zone of bright stars seems to gird the sky intersecting with the Milky Way at the Southern Cross, and manifest at all seasons, although far more conspicuous upon the *Orion* side than on the other. Upon my return to the North, I sought immediately for the northern place of intersection; and although the phenomenon is by far less clearly perceptible in this hemisphere, I found no difficulty in recognising the node in the constellation *Cassiopeia*, which is diametrically opposite to *Crux*. Indeed it is easy to fix the right ascension of the northern node at about 0h. 50m., and that of the southern one at 12h. 50m.; the declination in each case about 60°, so that these nodes are very close to the points at which the Milky Way approaches most nearly to the poles. The inclination of this stream to the Milky Way is about 25°, the Pleiades occupying a position midway between the nodes."

Gould also had no difficulty in showing that the group of the fixed stars to which I have just referred, at all events of fixed stars brighter than the fourth magnitude, is more symmetrical in relation to this new star line than to the Milky Way itself, and that the abundance of bright stars in any region of the sky is greater as the distance from this new star line becomes less. Practically five hundred of the brightest stars can be brought together into a cluster, independent of the Milky Way altogether—a cluster he points out of somewhat flattened and bifid form.

Not only do we find that the stars are very much larger in number near the Milky Way than elsewhere, but that the same thing happens with regard to the planetary nebulæ. Nebulæ generally, I am sorry to say, I cannot profess to discuss with any advantage, because there are very many bodies classed as nebulæ in the different catalogues about which we know absolutely nothing as to their physical nature. It will be remembered that many years ago the question of the real existence of nebulous matter in space was rendered very difficult by the fact that the larger telescopes, which were then being made by Lord Rosse, brought before us a great number of clusters, the stars of which were so close together that they seemed to form a nebulous patch, whereas on a finer night or with a better instrument we were able to see that we were simply dealing with distant clusters. I do not propose, therefore, to say anything about nebulæ generally, but to call attention to those points about which we can be most certain.

[1] *Amer. Jour. Sci.*, viii. p. 332.

We do know that, not only do we find stars increasing in number as the Milky Way is approached, but the undoubted star clusters also increase towards the Milky Way in a marvellous manner.

Bauschinger[1] (1889) in a review of Dr. Dreyer's New General Catalogue (7840 objects) discussed the distribution of different classes of objects and found that star clusters, by which he means of course resolved clusters, and planetary nebulæ congregate in and near the galaxy.

Mr. Sydney Waters some four years later, in 1893, brought together the nebulæ and the star clusters for us, and I propose to show the very important maps which he drew. He indicates a star cluster by a cross, and nebulæ by round dots. Practically the obvious star clusters are limited to the Milky Way. That is a very admirable way of bringing the knowledge with regard to any one of these distinct groups of stars before us, and it shows us in a most unmistakable manner that the star clusters, like the planetary nebulæ and stars generally, are very much more numerous in the plane of the Milky Way than they are in any other part of the heavens.

It is striking to note the fidelity with which the clusters follow, not only the main track of the Milky May, but also its convolutions and streams, while the remarkable avoidance of the galaxy by the nebulæ, excluding the planetary nebulæ, is obvious, indeed, it was remarked upon by Sir Wm. Herschel.

We have seen, then, that we have the greatest number of stars congregating in the plane of the Milky Way, the greatest number of planetary nebulæ and the greatest number of star clusters. We have next to consider whether any particular kind of a star congregates in the Milky Way or avoids it. In that way we shall be able to see the importance of this new chemical touch, which is now possible to us in our survey of the heavens.

The first attempt at such an inquiry as this was made in 1884 by Dunér,[2] who had made himself famous by his admirable observations on two different classes of stars—those which I have referred to as being defined by carbon flutings in one case and metallic flutings in the other. His work was practically the only research on the carbon stars—the stars, that is, with carbon flutings. He was, naturally, anxious to see how they were distributed, and he gives the number of these stars in varying parts of the heavens in relation to the Milky Way. He found that the numbers increased towards the Milky Way. The table I give will show the general result at which he arrived. We had, as we saw in the case of the ordinary stars, a very rapid progression in number from the pole of the Milky Way to the plane; we had three stars at the pole when we had fifty-three in the plane.

Dist. from galactic pole.	Number.	Mean mag.
° ° 0-35	3	6·6
35-60	8	6·6
60-70	8	7·2
70-80	13	7·4
80-90	29	8·3

Dunér found, with regard to his carbon stars, that there was distinctly an increase from the pole towards the plane, but we observe that the rate of increase was very much less in this case; so that, starting with three at the pole, he only found twenty-nine in the plane. Although then it was true that the number of stars did increase towards the Milky Way, they did not increase so rapidly as the stars taken as a whole; still, from his observations, we are justified in stating that

[1] *V.J.S. Ast. Ges.*, xxiv. p. 43.

[2] "Étoiles de la troisème Classe," p. 125.

there is an increase as we approach the plane of the Milky Way. They are, therefore, not limited to the plane. Now we know that these stars are the moribund stars, the stars just disappearing, the stars whose light is waning; so that soon after the carbon stage they exist in the heavens as dark stars, and we can only know their existence by their gravitational effect upon other stars which are self-luminous. It is also to be borne in mind that these stars, just because they are in their waning

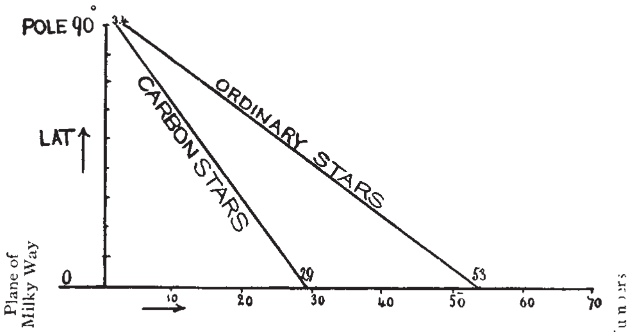

FIG. 2.—Comparison of relative numbers of stars generally and carbon stars.

stage, are very faint; so that the information we are able to get with regard to them may possibly be information concerning their distribution in parts of space not very far distant from that which we ourselves occupy.

That was in 1884. In 1891 Prof. Pickering, when he found that he had collected something like 10,000 stars in the Draper catalogue, began to consider their distribution in different parts of space in relation to the then classification, which was practically a classification founded on hieroglyphics, since we knew very little about the chemistry of the different bodies at that time.

He found that the Milky Way was due to an aggregation of white stars, by which he meant, as we now know, very hot stars, and the hottest of them, that is the gaseous ones, exist more obviously in the Milky Way than do the others. The proportional number of proto-metallic stars in the Milky Way was greater for the fainter stars than for the brighter ones of this kind, and that at once suggests a possibility that in the Milky Way itself there is a something which absorbs light; so that the apparently brightest stars are not actually the brightest, but are more luminous because they have not suffered this absorption, and that those which have suffered this absorption may be very much further away from us than the others of a similar chemistry. He also arrived at this extremely important conclusion, namely, that the metallic stars, that is, stars like our sun, stars more or less in their old age, had no preference for the Milky Way at all, but are equally distributed all over the sky. With regard to the group of stars known by metallic flutings in their spectra, he has no information to give us any more than Dunér had, for the reason that their number is small and they have not yet been completely studied.

Only last year this inquiry was carried a stage further by Mr. McClean, who not only photographed a considerable number of stellar spectra in the northern hemisphere, but subsequently went to the Cape of Good Hope in order to complete the story with reference to the stars down to the third or fourth magnitude, which he could observe there. He was very careful to discuss, in relation to the Milky Way and certain galactic zones, the distribution of the various kinds of stars which he was fortunate enough to photograph.

We notice that if we deal with the gaseous stars the numbers in the north and south polar region are small, and that the numbers nearer the Milky Way are greater, so that finally we can see exactly how these bodies are distributed. If we take the gaseous, that is to say the hottest, stars, we find the smallest number in the polar regions; but if we take the metallic stars we find practically the largest number, at all events a considerable number, in the polar regions. The general result, therefore, is that the gaseous stars are mostly confined to the galactic zones, the proto-metallic stars are not so confined, that is to say, down to about 3½ magnitude. What is also shown there is that the metallic-fluting stars are practically equally distributed over the polar regions and over the plane of the Milky Way itself; so that, in that respect, we get for these stars very much the equivalent of the result arrived at by Dunér, that is to say, they have little preference for the Milky Way.

(To be continued.)

THE PARENT-ROCK OF THE SOUTH AFRICAN DIAMOND.[1]

DIAMONDS were discovered in gravels of the Orange River in 1867, and were traced three years later to a peculiar earthy material called from its colour "yellow ground" by the miners. This, which was soon found to pass down into a more solid and dark-coloured material called "blue ground," occupies "pipes" in the country rock—carbonaceous shales and grits belonging to the Karoo system; the one standing in much the same relation to the other as do the volcanic necks to the carboniferous strata in Fifeshire. Flows or sills of basaltic rocks are associated with the sedimentary strata, and both are cut by dykes. The matrix of the blue ground is a fine granular mixture, chiefly consisting of a carbonate (calcite or dolomite) and serpentine. In this are embedded grains of garnet (mostly pyrope), pyroxenes (a chrome diopside, smaragdite or enstatite), a brown mica, magnetite and other ores of iron, and some other minerals more sparsely distributed. Rock fragments also occur; some of them are the ordinary shale and grit, but others are compact and of an uncertain aspect. Crystalline rocks are sometimes found.

As to the nature of this blue ground and the origin of the diamond, very diverse opinions have been expressed. The late Prof. Carvill Lewis considered the former to be a porphyritic peridotite, more or less serpentinised, which sometimes passed into a breccia or a tuff, and the diamond to have been formed *in situ* by the action of this very basic igneous rock upon the carbon present in the Karoo beds. Others, however, maintained that the rock was truly clastic; being produced by the explosive destruction of the sedimentary rocks, together with part of their crystalline floor—was, in fact, a kind of volcanic breccia, subsequently altered by the action of percolating water at a high temperature. But they also differed in opinion as to the genesis of the diamond itself; one party holding it to have been formed *in situ*, by the action of water at a high temperature and pressure, the other considering it, like the garnets, pyroxenes, &c., to have been formed in some deep-seated holocrystalline rock mass, and to have been set free, like them, by explosive action.

A few months ago the investigation had advanced thus far: (1) study of the diamonds obtained from the blue ground had increased the probability of their being derivative minerals; (2) no certain proof of the former existence of a compact or glassy peridotite had been discovered; (3) certain compact rock fragments, as to the origin of which the writer had at first hesitated to express an opinion, had been determined by him to be only argillites, affected first by the action of heat, then of water; (4) the diamond and the garnet had been brought into very close relation by the discovery of two specimens, showing the former apparently embedded in the latter. The better of them was accidentally picked up at a depth of about 300 feet in a shaft at the Newlands Mines, West

[1] The substance of a paper read before the Royal Society on June 1.